RELOCATION OF GLOBAL EVENTS USING THE L1-NORM AND SOURCE SPECIFIC STATION TERMS

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ABSTRACT

We relocate 99,715 global seismic events from 1964 to 1998 using the L1-norm and the source-specific station term method of *Richards-Dinger and Shearer* (1999). We use both regional and teleseismic P, *S*, *pP*, *PwP* and *sP* phase picks from the International Seismological Centre (ISC) as reassociated and corrected by *Engdahl et al.* (1998). Data from over 13 million picks are converted to a special compressed format that permits rapid storage and retrieval. Locations are obtained using an iterative grid-search method based on the L1-norm that is robust with respect to data outliers. We apply empirical corrections for three-dimensional velocity structure by computing spatially varying station terms using an iterative procedure in which travel time residuals at each station are smoothed over adjacent events. We compare our results to previous catalogs and to selected events of known location.

Key Words: seismic event location, grid-search methods

OBJECTIVE

To develop and implement new methods for locating global and regional seismic events with improved location accuracy and reliability. More accurate event locations will help to discriminate between earthquakes and explosions and will reduce the required search area for possible on-site inspections associated with monitoring of the Comprehensive Nuclear-Test-Ban Treaty.

RESEARCH ACCOMPLISHED

Introduction

Earthquakes are routinely located by comparing observed arrival times of *P* and *S* phases with those predicted by a reference velocity model and identifying the best-fitting event locations and origin times. Inaccuracies in the assumed velocity model will introduce systematic errors into the locations; these errors are typically more significant than the mostly random errors caused by phase timing uncertainties. For example, lateral velocity variations related to three-dimensional Earth structure will bias event locations derived using a one-dimensional velocity model. These errors can be divided into two different categories: (1) absolute location errors in individual events, and (2) relative location errors among nearby events. Addressing the problem of absolute location errors requires solving for an improved velocity model; this is the approach used in joint-hypocenter-velocity (JHV) inversions.

Improvements in relative locations among events, however, can be achieved without solving for a new velocity model. This has been accomplished using a variety of techniques, including joint epicenter determination, station term, and master event methods [e.g., *Douglas*, 1967; *Evernden*, 1969; *Lilwall and Douglas*, 1970; *Frohlich*, 1979; *Jordan and Sverdrup*, 1981; *Smith*, 1982; *Pavlis and Booker*, 1983; *Viret et al.*, 1984; *Pujol*, 1988]. These methods are most effective when applied to a relatively compact cluster of events, so that the travel-time perturbation to each station is approximately constant among the different events. Of these approaches, perhaps the simplest and most widely applied is to solve iteratively for a custom set of station timing corrections (commonly called "station terms"); this is the method described by *Frohlich* [1979].

For localized clusters of events, these techniques often lead to a dramatic improvement in relative location accuracy (although the absolute location of the entire cluster remains poorly constrained). As the events become more distributed, however, these methods become less effective because a single set of station terms can no longer adequately describe the full effect of the three-dimensional velocity variations. For optimal results, a different set of station terms is required for each source region. Researchers studying ways to improve earthquake locations have given these terms various names, such as "source specific site corrections" (SSSC), and "correction surfaces." If calibration events of known location are available, then improvements in absolute location accuracy can be achieved by suitable spatial interpolation of these terms [e.g., *Cogbill and Steck*, 1997; *Schultz et al.*, 1998].

Here we experiment with a new method for computing source-specific station terms (hereafter termed SSSTs) that we first applied to relocate earthquakes in southern California [*Richards-Dinger and Shearer*, 1999]. The method is capable of simultaneously locating large numbers of earthquakes and achieving, on a local scale, relative location accuracy comparable to master event techniques even when uniformly applied over a large area. Essentially our approach is to compute station terms for each event by smoothing the residuals from nearby events, and then iterating until a stable set of locations and station terms is achieved.

We apply our method to relocate nearly 100,000 earthquakes in the *Engdahl, van der Hilst and Buland* [1998] catalog (here termed the EHB catalog). Our preliminary results are not dramatically different from the EHB locations, although in some areas our relocated earthquakes show a greater tendency to group into clusters and align into linear and planar features. The absolute location accuracy, as measured by comparison to over 100 "ground truth" events, is not significantly different than that obtained by EHB.

Data and Processing

We use as our starting point the reassociated ISC phase picks of *Engdahl et al.* [1998], consisting of about 13.5 million *P*, *Pn*, *pP*, *pwP*, *S* and *sP* phases from 99,715 events (1964 to 1998). Before further processing, we convert the arrival time information to a special binary format that saves disk space and I/O time. The processed data set consumes 227 Mbytes and can be read into memory in 25 s on a typical workstation.

We relocate each event using a grid-search method based on the L1-norm [*Shearer,* 1997; *Richards-Dinger and Shearer*, 1999]. The L1-norm has the advantage of being more robust with respect to bad picks than conventional least-squares (L2-norm) techniques. We use the EHB corrections for ellipticity, bounce-point topography and water depth, and patch-averaged station terms. We exclude *S* arrivals at ranges beyond 80° to avoid confusion with *SKS*. Source-specific station terms (SSSTs) are obtained iteratively according to the following steps:

(1) Set the SSST for each event-station-phase combination to zero.

(2) Locate the events using the L1-norm and the appropriate SSSTs.

(3) For each event-station-phase combination, identify the closest *N* events that have picks from the same station-phase combination. Calculate the SSST for the event-station-phase combination by computing the median residual over the *N* adjacent events.

(4) Repeat steps (2) and (3) until convergence is achieved (i.e., there is no significant change in either the locations or the SSSTs.

In this way, we obtain station correction surfaces that vary smoothly as a function of source location (in both position and depth), with the degree of smoothing determined by the choice of *N*. The SSSTs so computed will adapt naturally to event density, averaging over larger volumes where seismicity is sparse and over smaller volumes in regions of dense seismicity. Our results presented here are for $N = 20$.

Relocation Results

We have obtained preliminary results for SSST relocations of the EHB data following four iterations for the location and station terms. Differences between these results and the EHB catalog are generally fairly small. In some areas, however, it appears that the SSSTs are successful in reducing the scatter in the locations, as illustrated by events near the Mendocino Triple Junction and the Tonga Trench (Figures 1 and 2). In each case the relocated seismicity shows a greater tendency to align into linear features. Since there is nothing in the algorithm that would cause this behavior, it is therefore likely that the method is providing a more accurate image of the actual seismicity patterns.

It should be emphasized, however, that these improvements are in relative location accuracy among nearby events. The absolute location accuracy is not affected by the SSST method. Analysis of 104 "ground truth" events of known locations [explosions and earthquakes obtained from *Kennett and Engdahl*, 1991; *Smith and Ekstrom*, 1996] indicates that the RMS location error is unchanged from the EHB catalog (approximately 21 km RMS).

CONCLUSIONS AND RECOMMENDATIONS

We have obtained preliminary results for a new global location scheme based on the L1-norm and source-specific station terms (SSSTs). Application of the method to the EHB catalog of reassociated ISC phase picks produces results comparable to the EHB locations, although in some cases the relative location accuracy appears improved as shown by reduced scatter in the positions of nearby events. Significant improvements in the absolute location accuracy of the method will require calibrating the SSSTs with ground truth events or incorporating three-dimensional velocity models.

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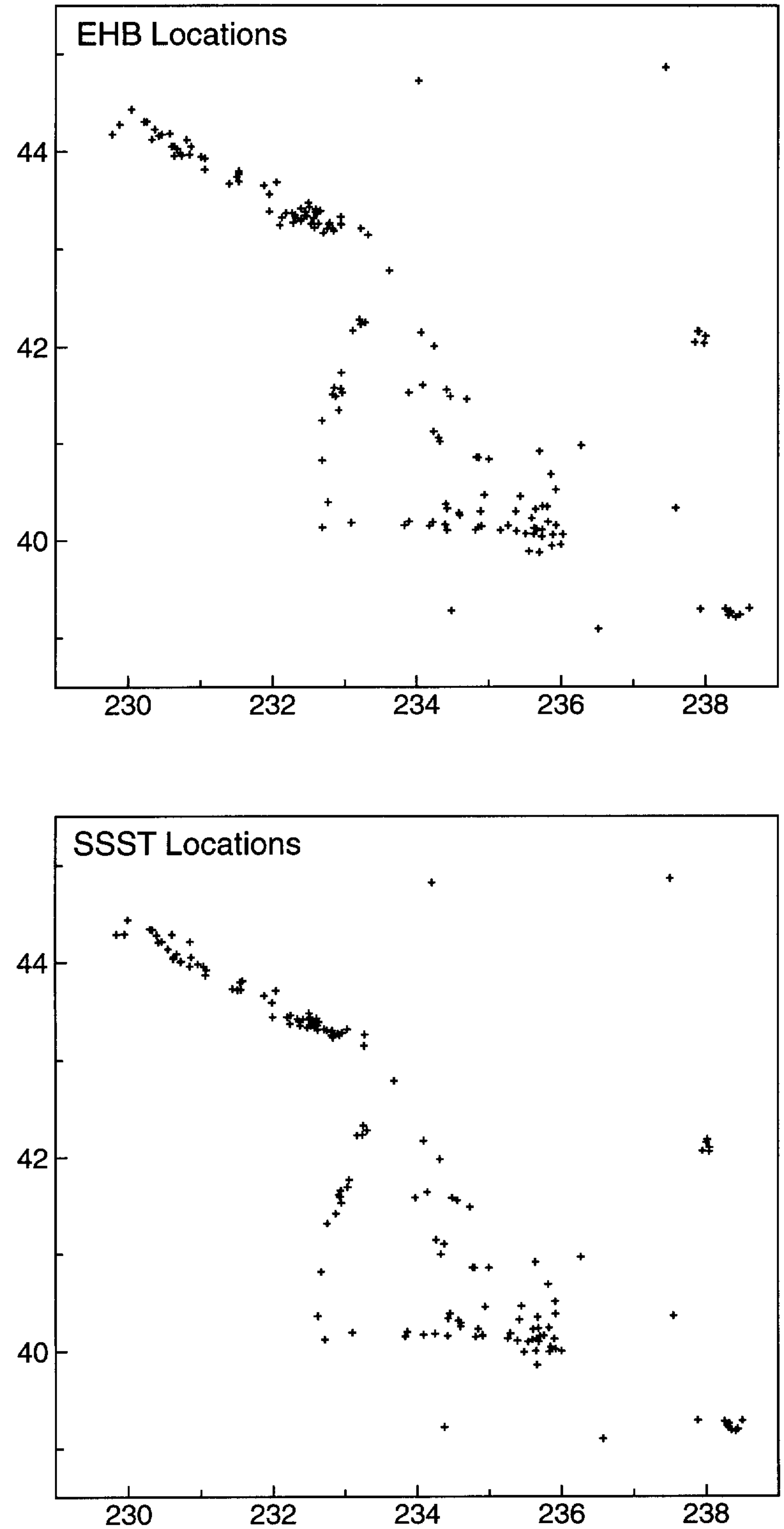

Figure 1. A comparison between EHB locations [*Engdahl et al*., 1998] and SSST locations for 157 events near the Mendocino Triple Junction, offshore Northern California. Note the reduced scatter in the SSST locations.

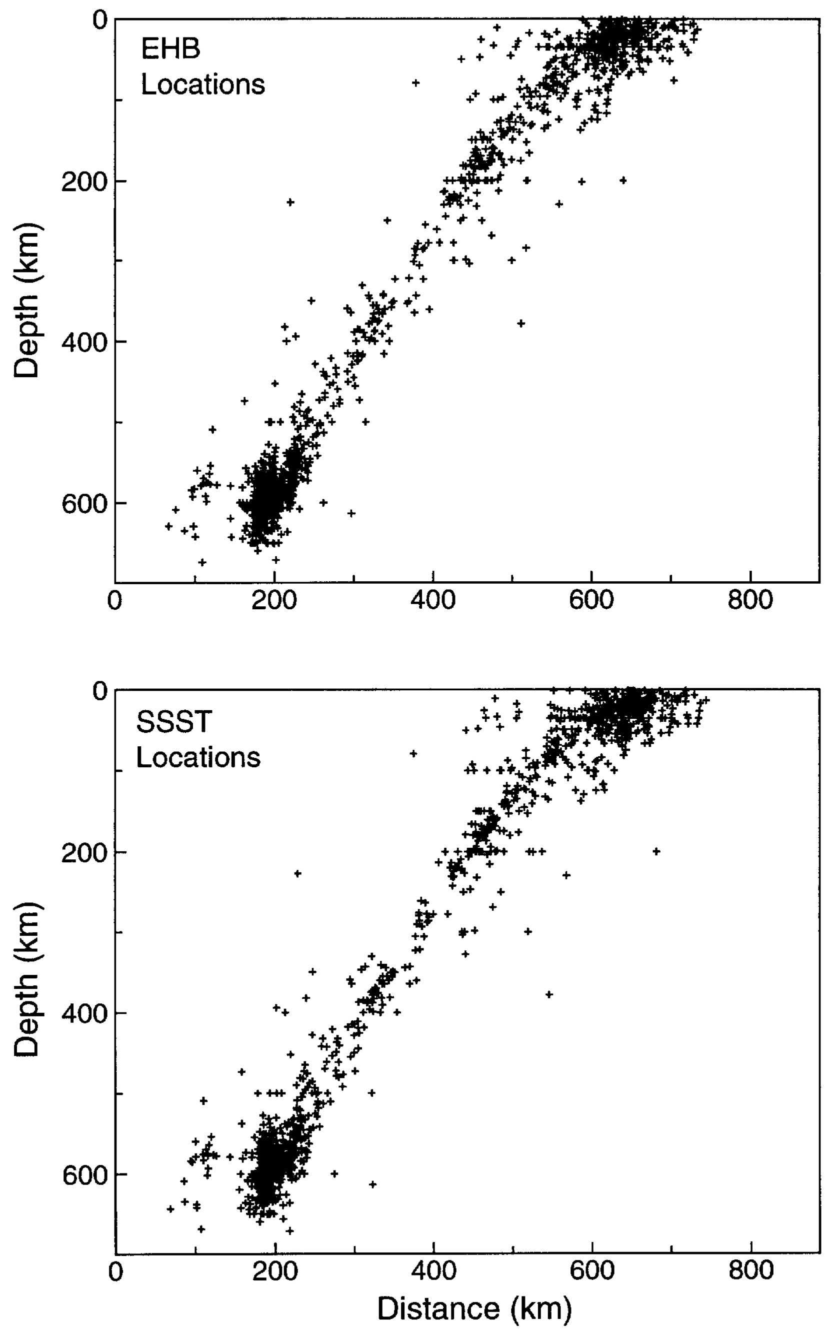

Figure 2. A comparison between EHB locations [*Engdahl et al.*, 1998] and SSST locations for 1385 events in the Tonga subduction zone. Endpoints are at (21°S, 179°E) and (24°S, 187°E); events are included that are within 1° of the cross-section.

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